Millimeter Emission Structure in the AU Mic Debris Disk

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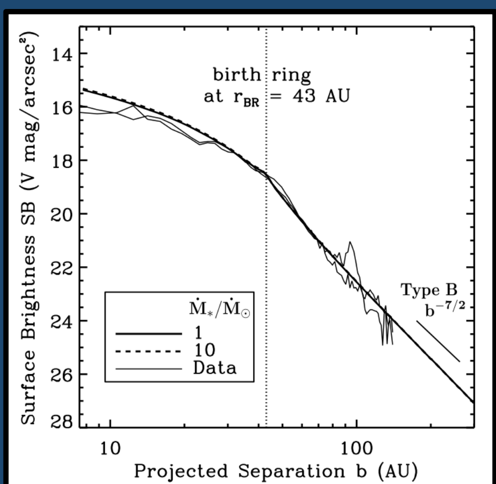
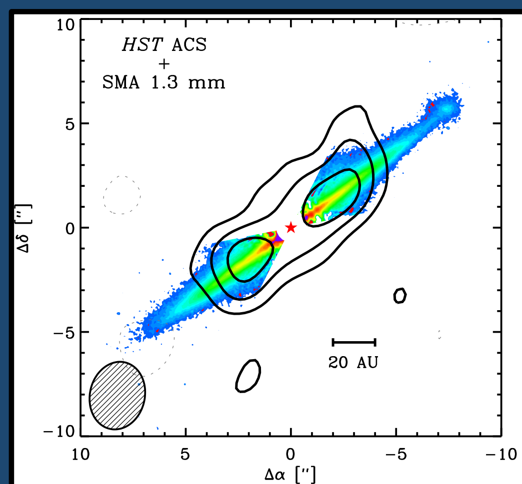
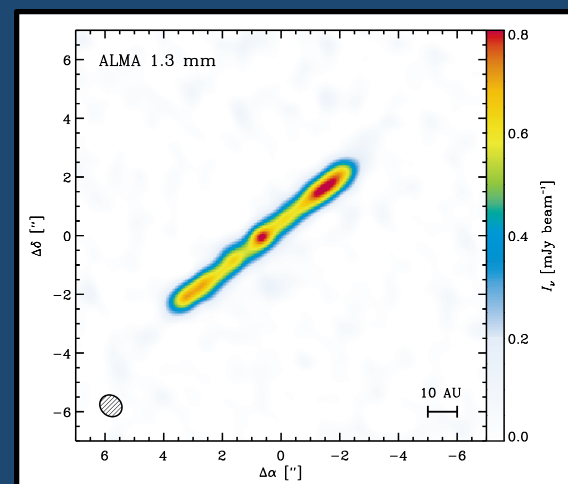
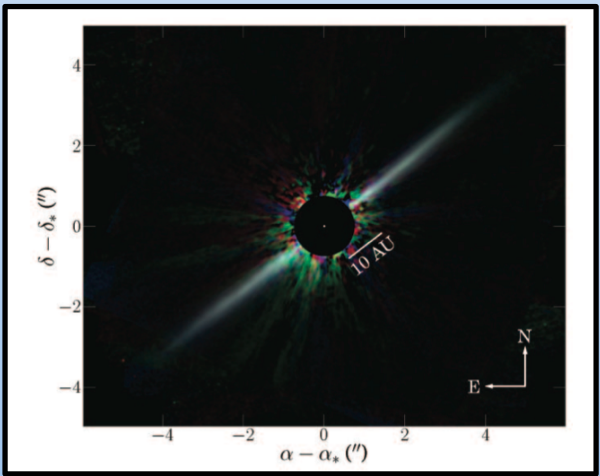


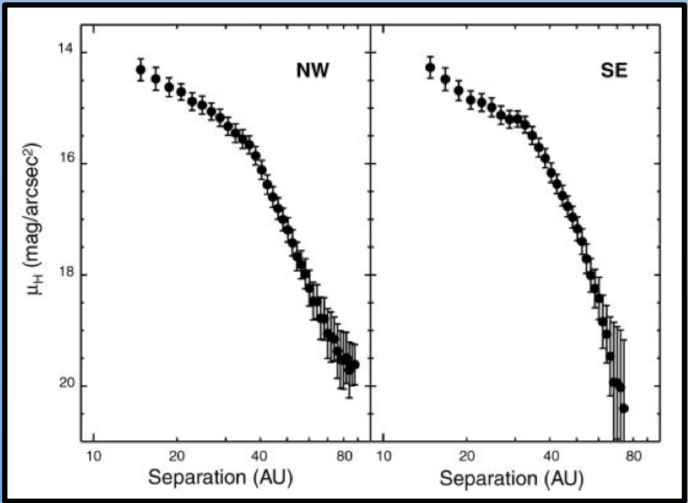




The Source: AU Mic



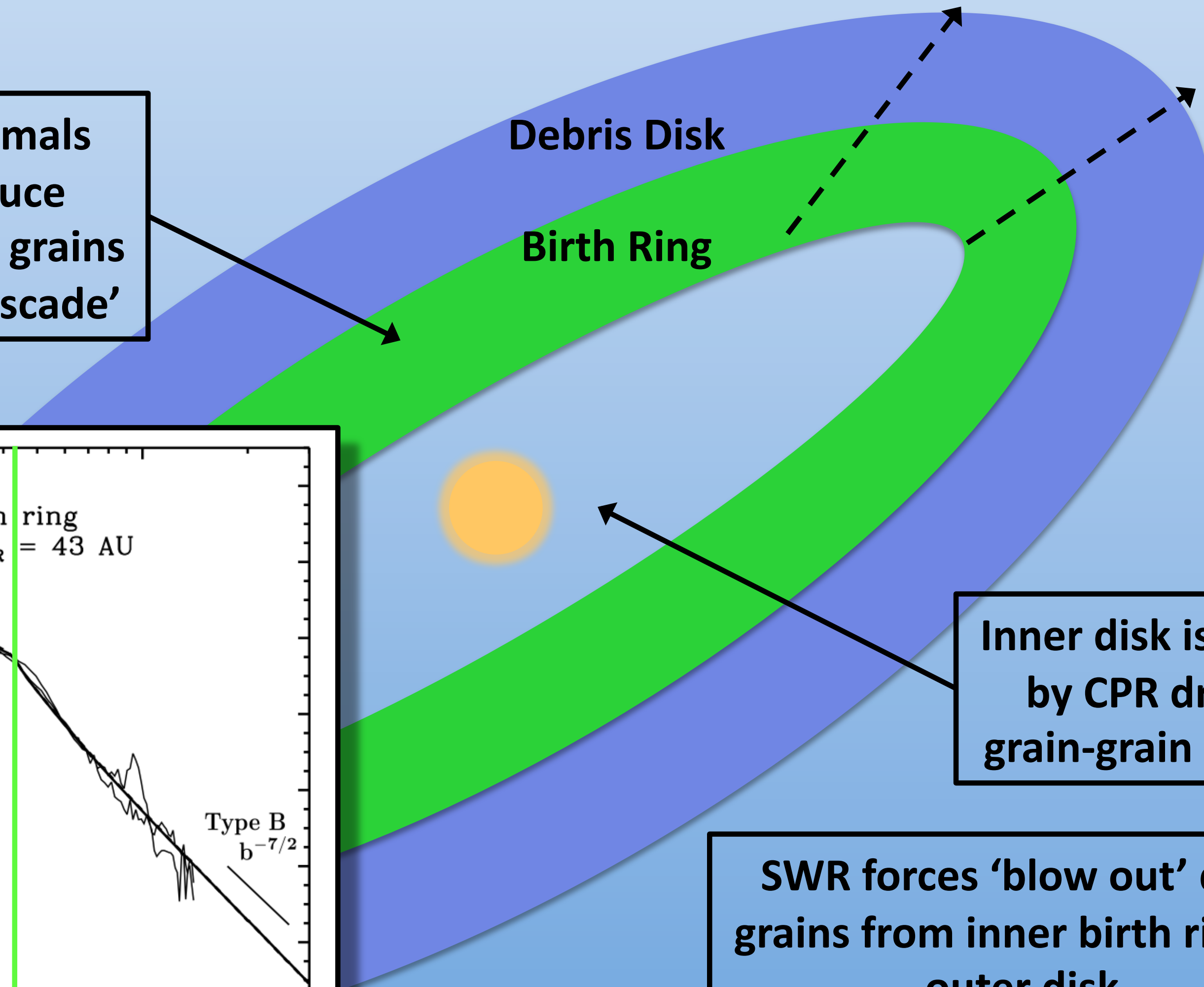
Fitzgerald et al. (2007)



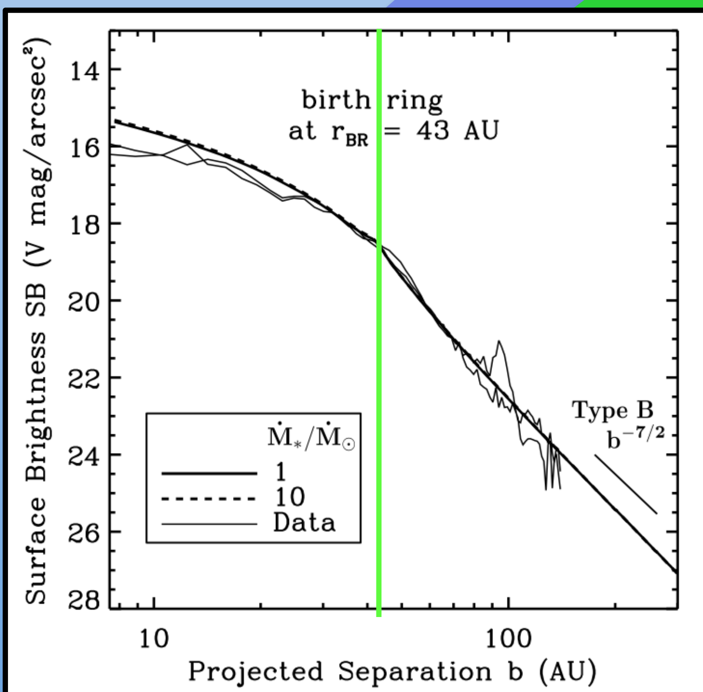
Liu (2004)

- Member of the β Pictoris Moving Group (9.91 pc, M star, ~12 Myr old)
- Edge-on geometry
- SB profile steepens in the outer disk
- For AU Mic, break occurs at r_{break}~ 30 – 40 AU
- Inferred H_2-to-dust ratios of ≤ 1/30 : 1 (France et al., 2007)

Birth Ring Theory



Larger planetesimals collide to produce micron-sized dust grains in a 'collisional cascade'



Inner disk is emptied by CPR drag and grain-grain collisions

SWR forces 'blow out' dust grains from inner birth ring to outer disk

Strubbe & Chiang (2006); Augereau & Beust (2006)

Observations with the SMA

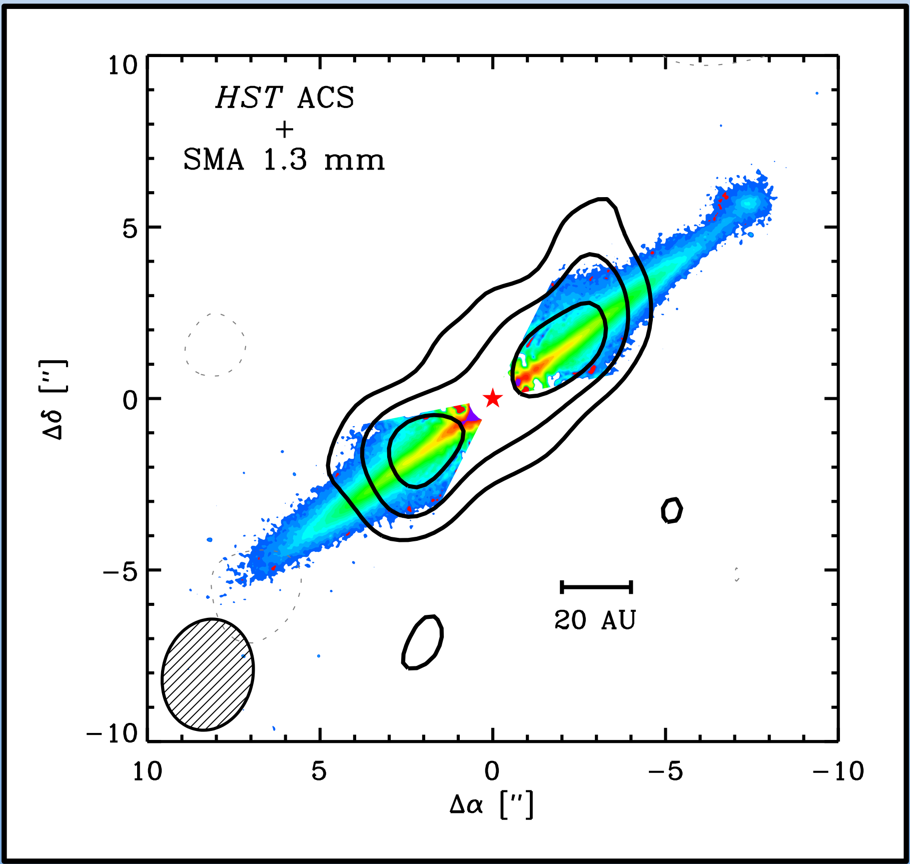
Wavelength: 1.3 mm

Synthesized beam:

~ 3"(30 AU)

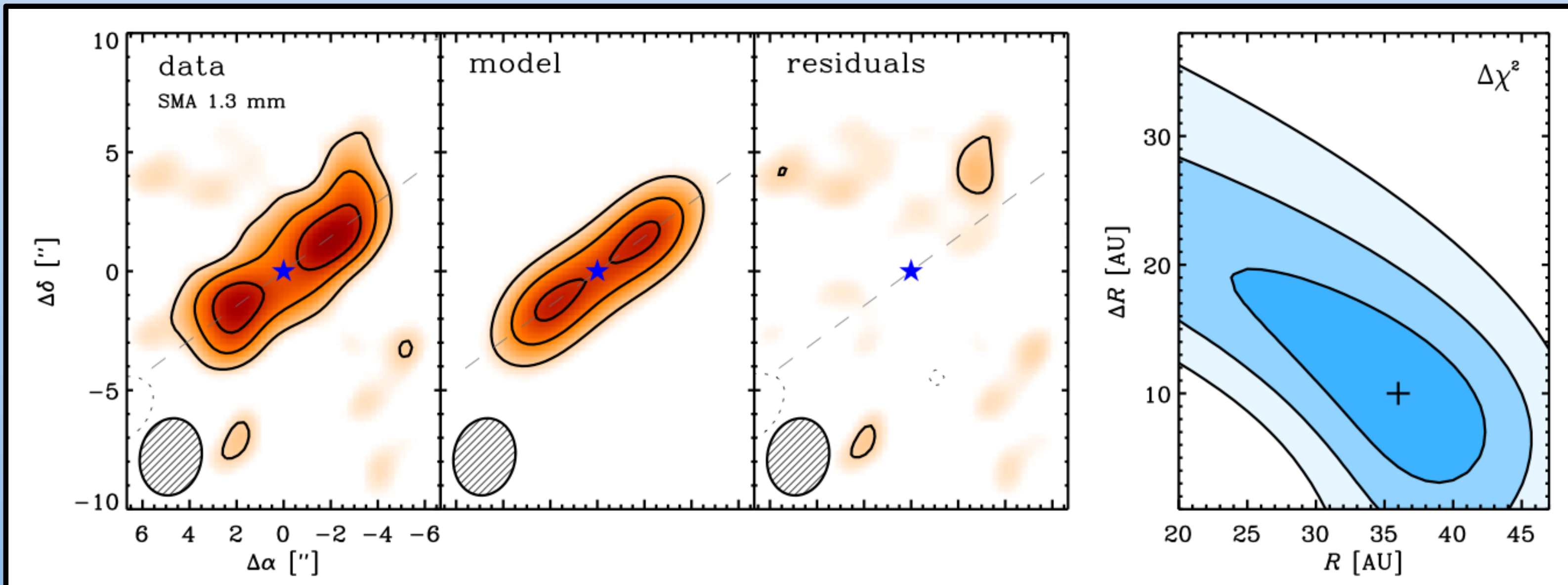
rms: 0.4 mJy beam^{-1}

Adopted a parametric modeling scheme by fitting the visibilities directly



Wilner et al. (2012)

Modeling Results



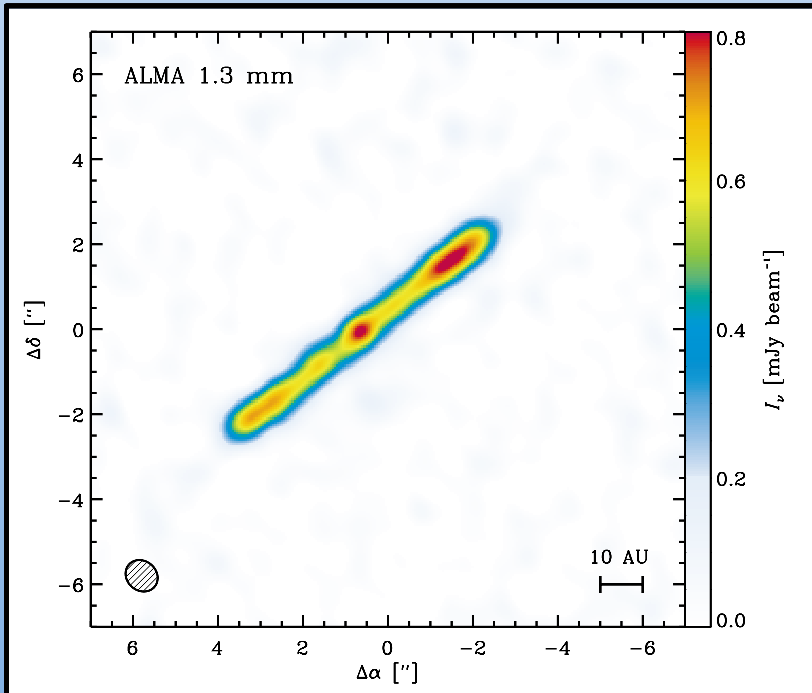
Wilner et al. (2012)

Results are consistent with theory

Parameter Fits:

R_{cen} = 36 (+7 / -16) AU
ΔR =10 (+13 / -8) AU
F = 8.0 ± 1.2 mJy

New ALMA Observations



MacGregor et al. (2013)

- Observed at **1.3 mm** (Band 6)
- Two-hour ‘scheduling block’ executed four times
- rms of **30 μJy beam^{-1}**
- Number of operational antennas: **16 – 20**
- Synthesized beam: **0.’’80 × 0.’’69** (8 × 7 AU)
- ALMA Project 2011.0.00142.S (Wilner), 2011.0.00274.S (Ertel)

Modeling Formalism

- Axisymmetric belt characterized by an annulus with radial intensity:

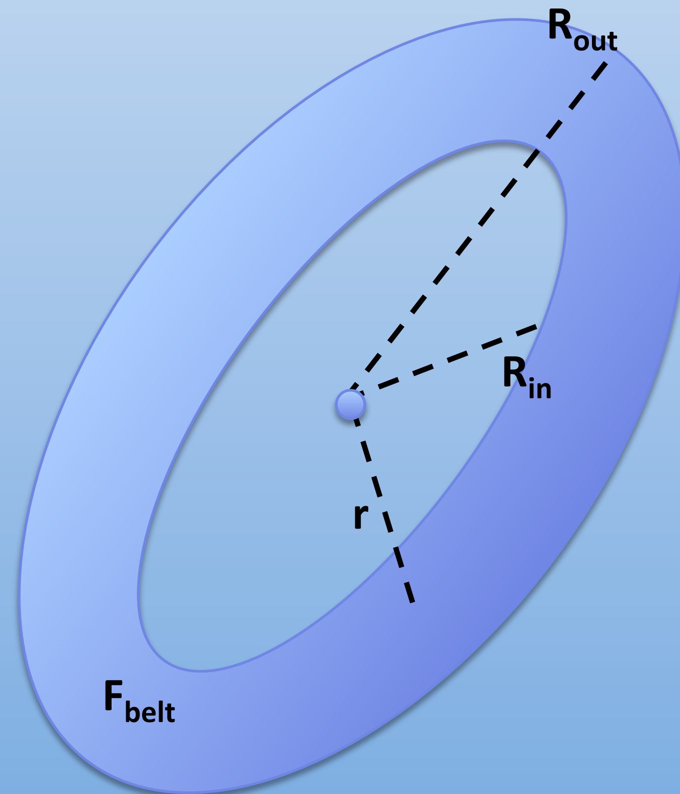
$$I_\nu(r) \propto r^x$$

for $R_{in} < r < R_{out}$

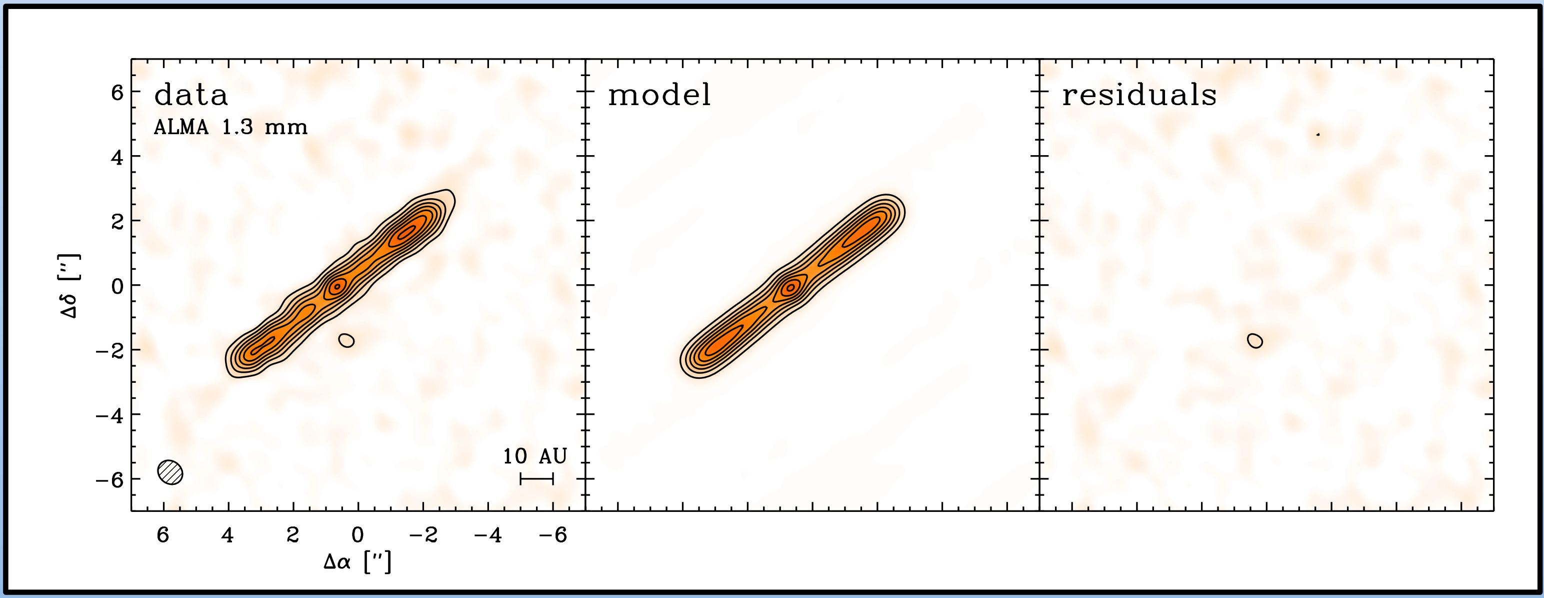
- Normalization given by:

$$F_{\rm belt} = \int I_\nu d\Omega$$

- Added a circular Gaussian to describe central component
- Adopted a Monte Carlo Markov Chain (MCMC) approach



Modeling Results



MacGregor et al. (2013)

Best-fit model has two distinct components:

1. An edge-on outer belt with an emission profile that *rises* with radius out to 40 AU
2. An unresolved peak at the center of the outer belt

Modeling Results

Table 2
Model Parameters

	Parameter	Description	Best-Fit	68% Confidence Interval
Outer Belt	$F_{\rm belt}$	Belt flux density (mJy)	7.14	+0.12, −0.25
	x	Belt radial power law index	2.32	+0.21, −0.31
	r_i	Belt inner radius (AU)	8.8	+11.0, −1.0
	r_o	Belt outer radius (AU)	40.3	+0.4, −0.4
	P.A.	Belt position angle (°)	128.41	+0.12, −0.13
	$\alpha_{\rm belt}$	Belt spectral index	−0.15	+0.40, −0.58
Central Peak	$F_{\rm cen}$	Gaussian flux density (mJy)	0.32	+0.06, −0.06
	$\Delta r_{\rm cen}$	Gaussian offset (AU)	0.71	+0.35, −0.51
	$\sigma^2_{\rm cen}$	Gaussian variance (AU^2)	$\leqslant$5.9	(3σ limit)
	$\alpha_{\rm cen}$	Gaussian spectral index	−0.35	+2.1, −4.5
	$\Delta\alpha$	R.A. offset of belt center (″)	0.61	+0.02, −0.02
	$\Delta\delta$	Decl. offset of belt center (″)	−0.03	+0.02, −0.02

The Outer Dust Belt

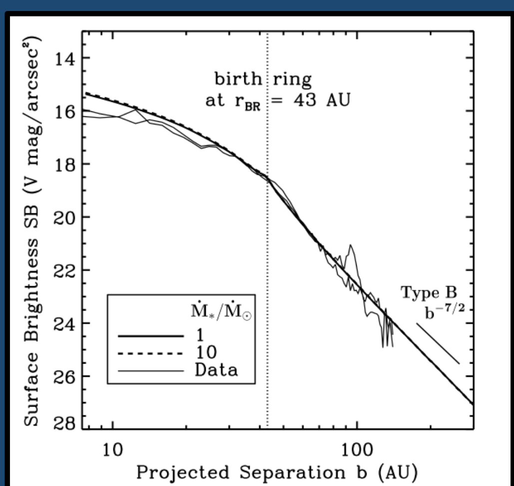
- **Position of far edge well constrained at R_{out} = 40 AU**
  - Outer belt parameters are in good agreement with the less well-constrained SMA fits
  - Matches closely outer edge of hypothetical "birth ring"
- **Kuiper Belt-like truncation of outer edge**
- **Rising emission profile with radial power-law index $x \approx 2.3 \pm 0.3$**
  - Implies rising surface density profile
  - Inner collisional depletion? (Kennedy & Wyatt, 2010)
- **No detectable asymmetries or substructure**
  - Still consistent with a Uranus-like planet (Mustill & Wyatt, 2009)

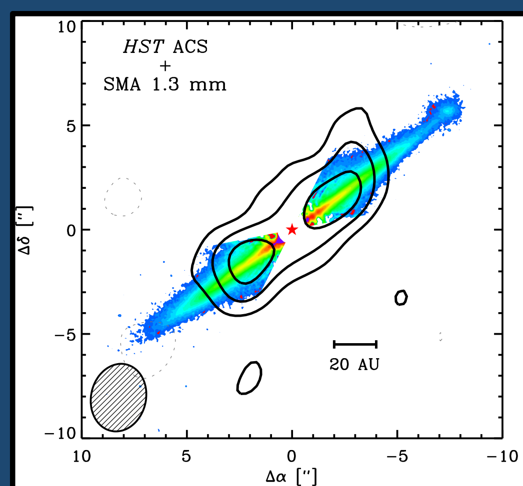
The Central Peak

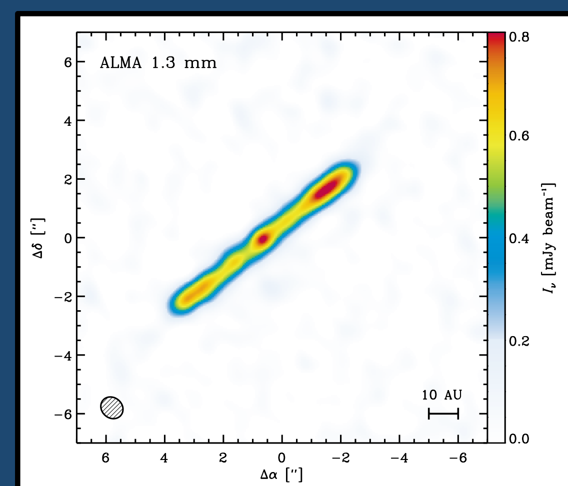
- **Stellar photosphere at 1.3 mm much fainter than observed flux from central peak**
  - Stellar model predicts F_* = 52 μJy, ~6x fainter than observed flux
- **Flares detected at ~200 – 1200 μJy at 6 cm**
  - Should have fast decay times (~1 hour)
  - Peak persists in all four ALMA SBs, but spectral index constraints are not good enough to be diagnostic
- **Stellar Corona?**
  - Could be tested with the VLA
- **Unresolved inner planetesimal belt within 3 AU of the star**
  - Temperature estimates from SED modeling comparable to expected for dust a few AU from the star

Summary

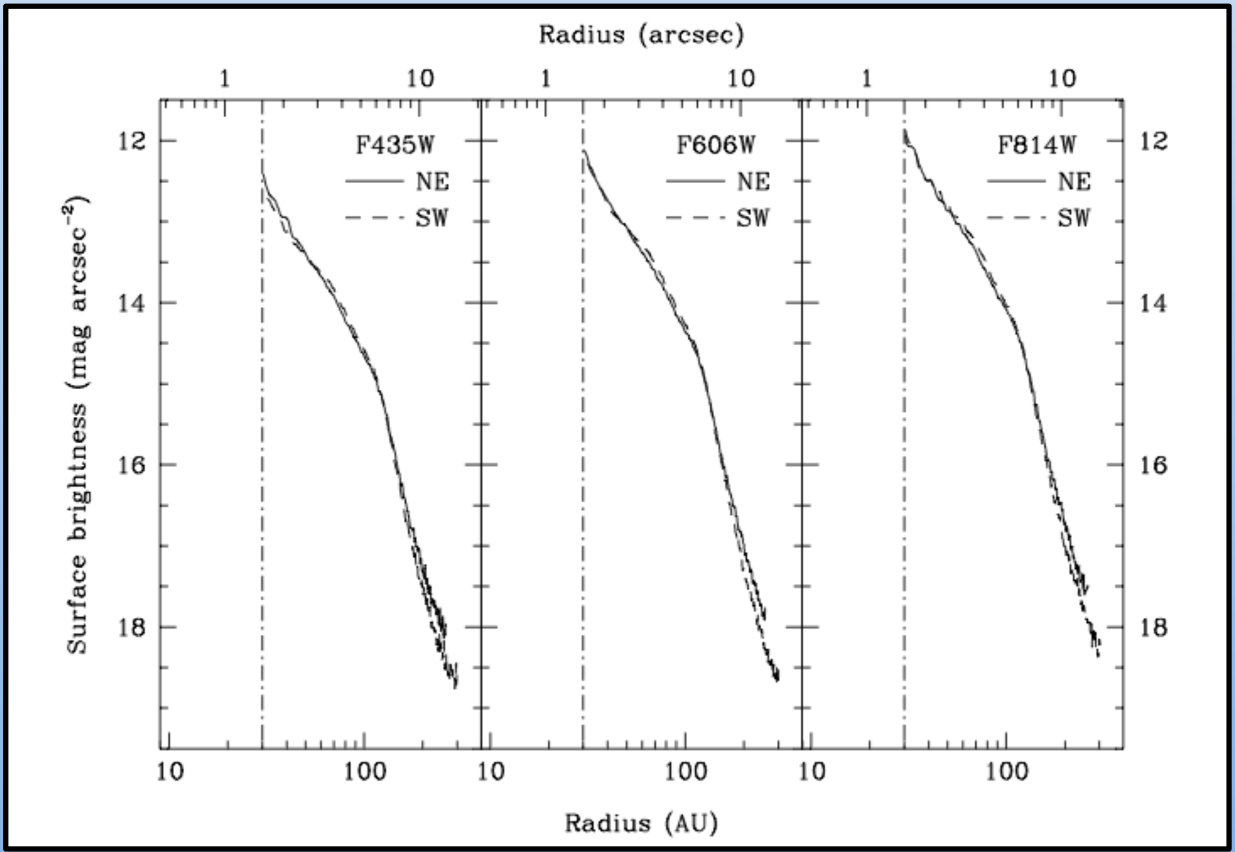
1. “Birth ring” theory explains AU Mic scattered light observations
2. Millimeter observations with the SMA reveal “birth ring” of planetesimals
3. ALMA provides a clearer view of the millimeter disk structure
4. Future ALMA observations will determine nature of central component







β Pictoris

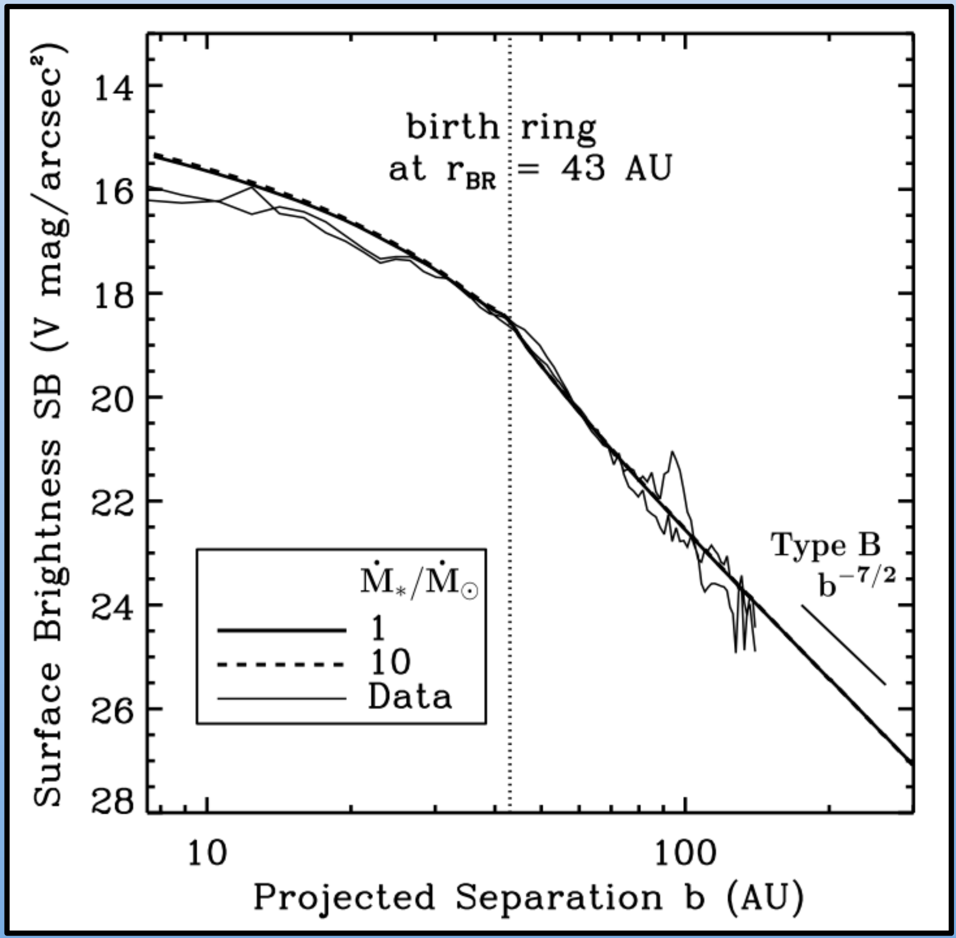


Golimowski et al. (2006)

Original example of break in the surface brightness profile indicative of 'birth ring'

Birth Ring Theory

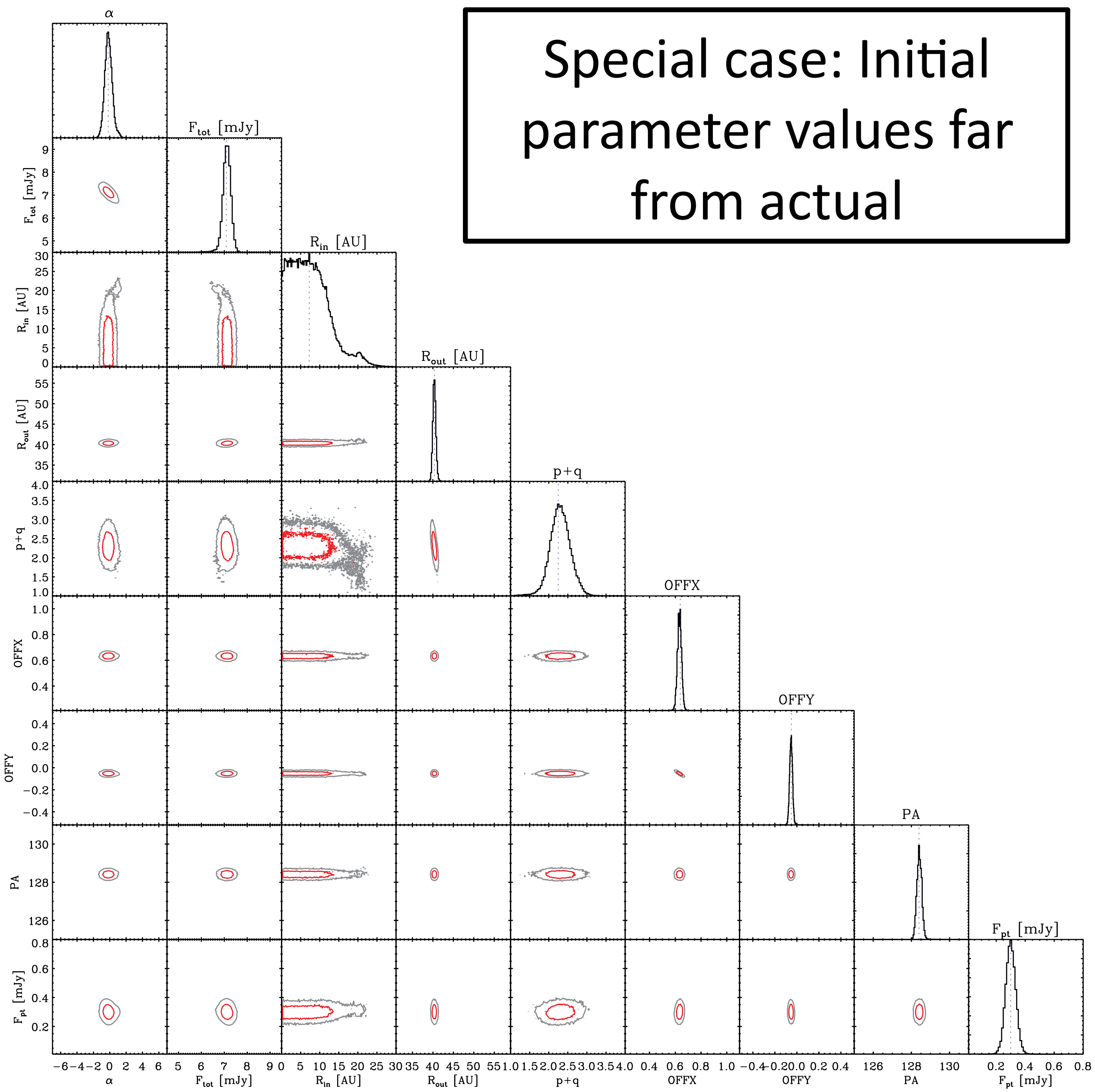
- Type B conditions: dominated by grain-grain collisions
- Winds dominate in the case of AU Mic as opposed to radiation pressure in the case of β Pic
- Inferred H_2-to-dust ratios of ≤ 1/30 : 1 (France et al., 2007)



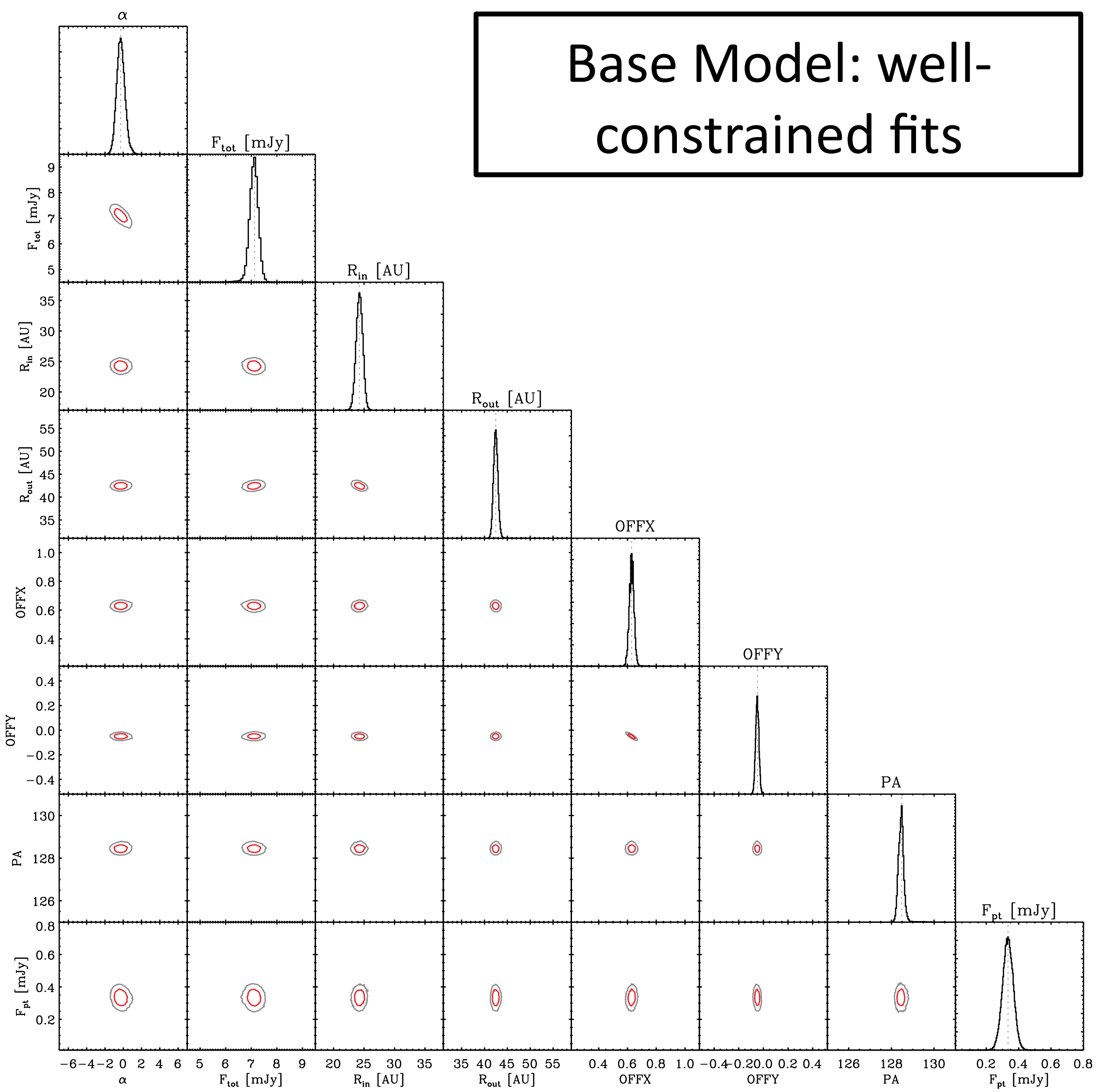
Strubbe & Chiang (2006)

MCMC Modeling

Special case: Initial parameter values far from actual

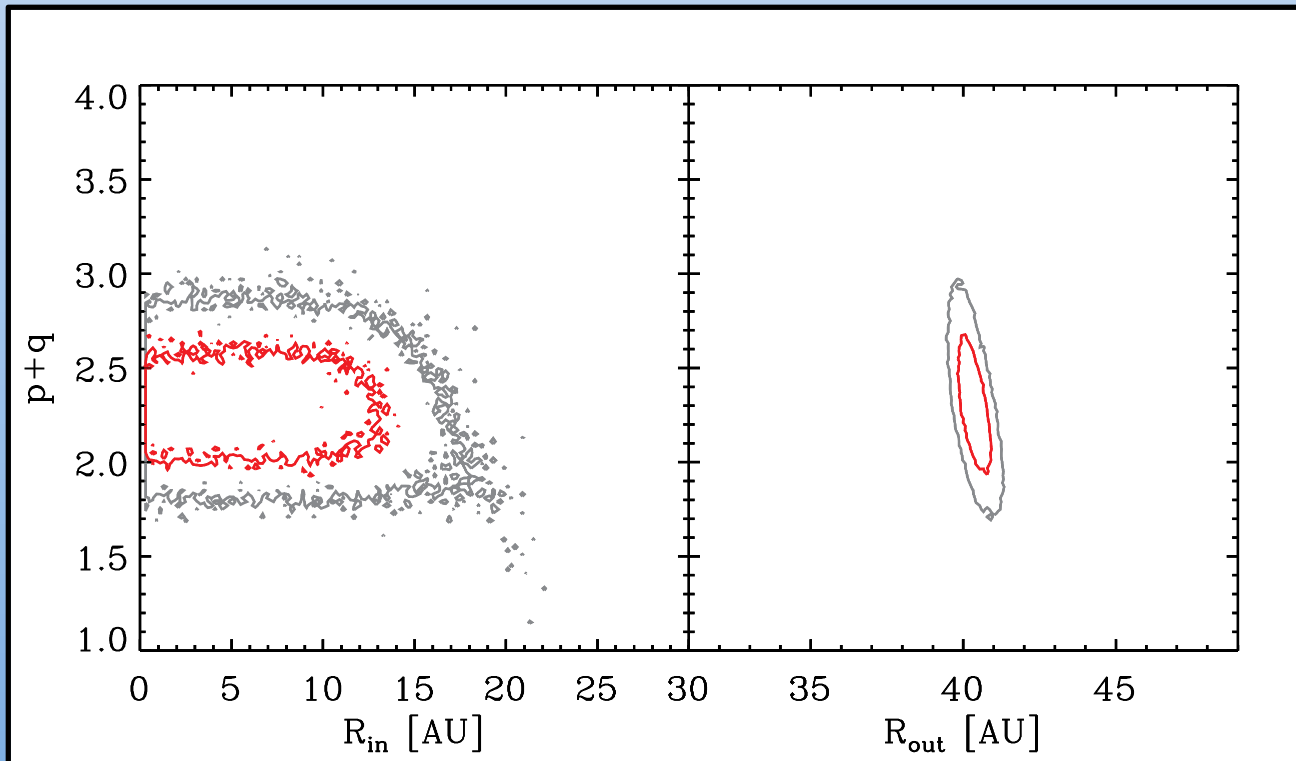


MCMC Modeling



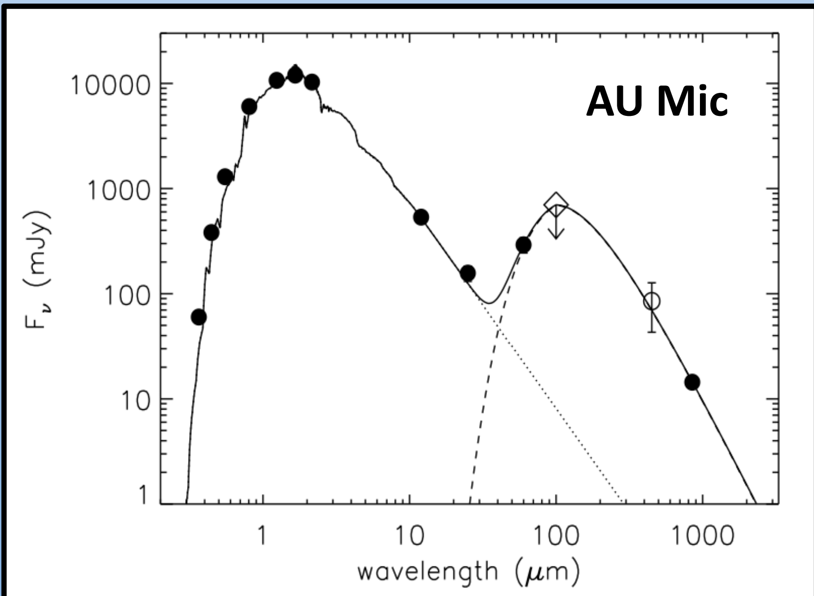
Base Model: well-constrained fits

MCMC Modeling



Comparison between a limit and a well-constrained fit

The Central Peak- Dust



Liu et al. (2004)

- Constrained the extent of the belt to $R_{cen} \leq 3$ AU (3σ)
- Estimated the highest temperature of this inner belt based upon what can be accommodated by the SED
  - For larger grains ($a_{max} \geq 1$ mm), can fit up to $T \approx 75$ K
  - Comparable to expected temperature for dust a few AU from the star